REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE Paper	3. DATES COVERED
4. TITLE AND SUBTITLE Development and Testing of the F/A-18 Replacement MIL-STD-1760 Umbilical		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Susan Jahn Greg Miller		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Air Warfare Center Aircraft Division 22347 Cedar Point Road, Unit #6 Patuxent River, Maryland 20670-1161		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The U.S. Navy F/A-18 aircraft currently uses a generic weapon umbilical cable with the new MIL-STD-1760 interface weapons. The existing cable has been shown to be problematic during weapon separation/integration testing and general fleet use. Modification of the existing cable was not feasible so redesign was required for replacement. The goals of the replacement cable design were to fix the specific problem areas of the existing cable as well as improving overall performance and service life. The service life goals for the umbilical were to be suitable for reuse for at least 25-30 releases. NAWCAD (4.11.2) developed a testing approach for qualification of the umbilical and to credibly assess service performance potential without specific airborne release tests. The qualification effort s discussed from an overall perspective as well as details of the lightning testing of the connector, static, and ejection testing, and captive flight testing of the cable. A short summary of post-certification efforts involving the umbilical is also given along with conclusions concerning the test effort.

15. SUBJECT TERMS

MIL-STD-1760; F/A-18; umbilical

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Susan Jahn / Greg Miller
a. REPORT	b. ABSTRACT	c. THIS PAGE		11	19b. TELEPHONE NUMBER (include area code) (301) 342-0271 / (301) 342-43113

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

20010406 112

Development and Testing of the F/A-18 Replacement MIL-STD-1760 Umbilical

Susan Jahn
Naval Air Warfare Center – Aircraft Division
Hgr 201 Suite 1A
21960 Nickles Road, Unit 4
Patuxent River, MD 20670
(301) 342-4339
JahnSB@navair.navy.mil

Greg Miller
Naval Air Warfare Center – Aircraft Division
Hgr 201 Suite 1A
21960 Nickles Road, Unit 4
Patuxent River, MD 20670
(301) 342-4313
Millermg2@navair.navy.mil

Abstract— The U.S. Navy F/A-18 aircraft currently uses a generic weapon umbilical cable with the new MIL-STD-1760 interface weapons. The existing cable has been shown to be problematic during weapon separation/integration testing and general fleet use. Modification of the existing cable was not feasible so redesign was required for replacement. The goals of the replacement cable design were to fix the specific problem areas of the existing cable as well as improving overall performance and service life. The service life goals for the umbilical were to be suitable for reuse for at least 25-30 releases. Naval Air Warfare Center – Aircraft Division (NAWCAD) 4.11.2 developed a testing approach for qualification of the umbilical and to credibly assess service performance potential without specific airborne release tests. The qualification effort is discussed from an overall perspective as well as details of the lightning testing of the connector, static and ejection testing, and captive flight testing of the cable. A short summary of post-certification efforts involving the umbilical is also given along with conclusions concerning the test effort.

Table of Contents

1. Introduction

The U.S. Navy F/A-18 aircraft currently uses the Generic weapon umbilical cable (P/N 74A756247-9AAA), with the new MIL-STD-1760 interface weapons such as the Joint Stand-Off Weapon (JSOW), Joint Direct Attack Munition (JDAM), Stand-Off Land Attack Missile-Expanded Response (SLAM-ER). The existing cable, originally designed to interface with the non-jettisonable AWW-13 Data Link Pod, has shown to be problematic during weapon separation testing, weapon integration testing, and general fleet use. Failure modes from a limited sample size study of approximately 47 cables from NAWCAD separation testing, NAWCWD (*Naval Air Warfare Center – Weapons Division)* weapon integration testing, and fleet cables are shown in Figure 1. Grouping the detailed breakdown of failures shown in Figure 1 by cable components, 48% of the failures were related to the MIL-STD-1760 connector (31% were lanyard related, 17% non-lanyard related), 67% were wiring failures, 6% were backshell fractures. This was considered pervasive failure areas across the cable. The number of failures was also excessive, 63 failures within this sample from the study as compared to the entire F/A-18 fleet failure history of the Harpoon Cable (25 failures over 7 years) and the LAU-115 Cable (70 failures over 5.8 years). Use of the existing cable during weapons development programs was presenting a persistent problem and resource drain that increased integration and test cost, increased schedule, and presented an Operational Evaluation (OPEVAL) risk.

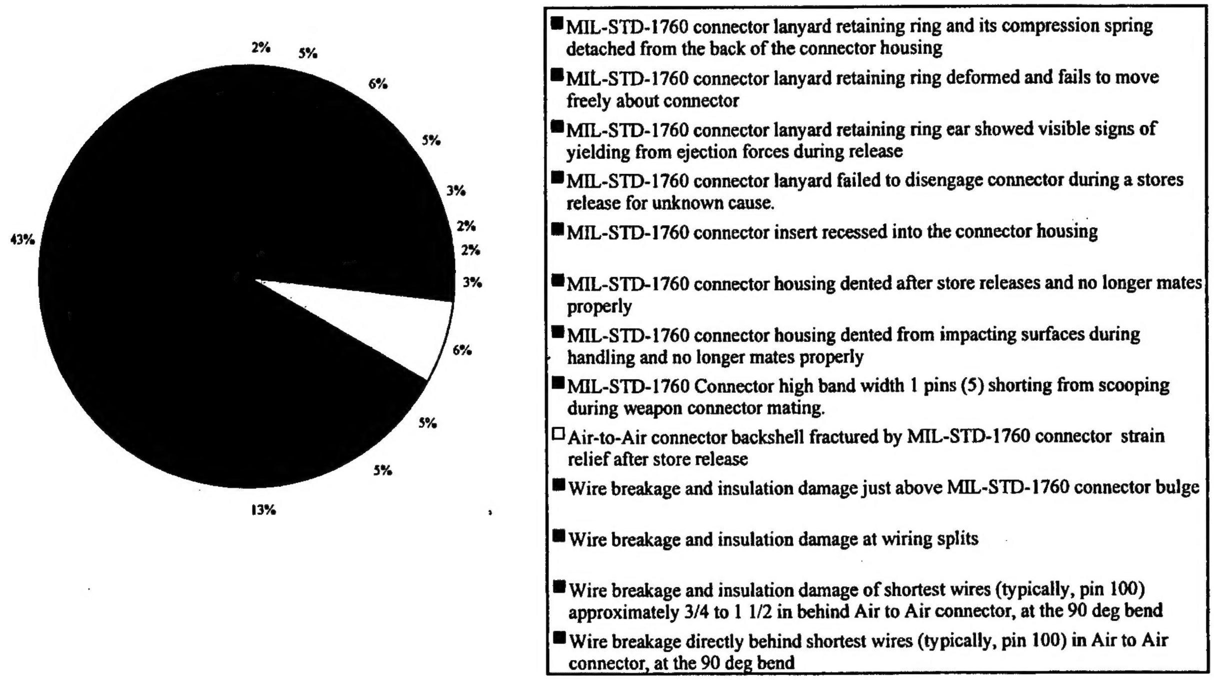

Figure 1 Generic Umbilical Failure Modes

2. Development of the Replacement

Modification of the existing cable was not feasible due to the pervasive failure areas, so redesign was required for replacement. NAWCAD 4.11.2 was tasked with developing a replacement cable. The goals of the replacement cable design were to fix the specific problem areas of the existing cable as well as improving overall performance and service life. The service life goals were to be suitable for reuse for at least 25-30 releases. The redesigned cable was constrained to the same production unit cost as the existing cable and to remain repairable at the intermediate level of maintenance. Performance improvements were made with technological insertion and cost as an independent variable trade-offs that included the following:

(1) Composite MIL-STD-1760 short barrel connector with Kevlar lanyard for lower cost, improved impact resistance, improved jamming resistance, and control of pull forces especially at high pull angles
(2) Composite low profile MIL-STD-1760 and Air to Air backshells for lower cost, improved impact resistance, and bulk reduction
(3) Added support at wiring joints for durability
(4) Spiral wires for strain relief and flexibility
(5) Reduced bulk throughout cable for improved fit with current and future weapons
(6) Pre-fabricated highly flexible wire bundle for increased cable flexibility for improved fit with current and future weapons and ease of assembly

3. Qualification Program

The qualification program for the replacement cable to gain approval for U.S. Navy fleet use focused on issues related to failure modes of the existing cable and technological improvements in lanyard release connectors and low weight flexible cable. The qualification program was used to ensure proper function of the cable and to estimate a realistic service life to serve as a basis for procurement decisions. The qualification program addressed several major issues:

- The use of composite connectors in an open pylon area and in a severe wind and moisture environment including F/A-18 flight effects, environmental effects, and lightning effects.
- The use of Kevlar as a lanyard material, including pull force effects, F/A-18 flight effects, environmental effects.
- The lanyard release performance and durability of the MIL-STD-1760 connector, especially during high pull angles.
- Wiring assembly durability with repeated installation/removal and F/A-18 in-flight effects on the assembly.

The qualification program consisted of the following tests:

- Fit Tests with current weapons
- Static Pull Tests
- Ejection Tests
- E3 (Electromagnetic Interference(EMI)/Electronic-Magnetic Compatibility(EMC)/Electromagnetic

Vulnerability(EMV), Shielding Effectiveness, Hazards of Electromagnetic Radiation to Ordnance (HERO), Lightning)
- Environmental Tests (High Temperature, Low Temperature, Humidity, Vibration, Salt-Fog)
- Electrical Compatibility Tests
- Post-Release Configuration Captive Carriage

Cable-specific airborne release tests were not included in the cable qualification program due to the high costs and asset requirements involved, confidence in the cable-specific ejection test methodology to predict inadequate lanyard release performance, and the intention to use the cable on subsequent separation test programs for F/A-18/MIL-STD-1760 stores. This paper will discuss the lightning, static pull, ejection, and captive carriage testing of the cable.

4. LIGHTNING TEST

Threat Scenario and Concerns

The lightning threat scenario at issue was a direct strike to the nose of the weapon, transmitted through the weapon to the aircraft via current paths (including the cable), traveling through the aircraft and exiting the tail of the aircraft. As such, direct lightning strikes to the cable itself were not considered to be a threat for this cable due to the cable location within the pylon bay and weapon attachment point. The ability of the composite components of the cable to withstand and remain functional when exposed to direct lightning effects as a major current path was the issue of concern. Indirect lightning effects are considered less severe and answerable by the direct effects issue. The existing composite MIL-STD-38999 Type III lanyard release connector lightning test results of reference [1] do not address the lightning threat representative of the F/A-18 wing pylon environment described above. They address diffusion and current redistribution effects found on conductors within aircraft carbon fiber composite material structures (Waveform 5B of reference [2]) vice lightning direct effects on a major current path (Figure 1 Current Components ABCD of reference [3]). Further testing tailored to the F/A-18 pylon environment with the composite connector and backshell were required.

Zone and Test Parameters

As previously described lightning threat scenario, the cable was a major current path for the lightning to traverse from the weapon to the aircraft and was considered Zone 3. Other major current paths were considered as follows (for a total of 5 current paths.

- Forward swaybrace and ejector foot units
- Aft swaybrace and ejector foot units
- Forward Lug/Hook Interface
- Aft Lug/Hook Interface

To provide a conservative simplifying assumption, all current paths were assumed of equal impedance. Zone 3 current levels were determined by analysis of all current paths that were in parallel with the umbilical cable and by apportioning the current from Figure 1 of MIL-STD-464 to each path. The waveforms used for Zone 3 tests were waveform "ABCD" of Figure 1 of MIL-STD-464. Documented lightning strike history of the F/A-18 showed that required avionics for store release were typically functional after a lightning strike, and as such the cable was not permitted to be the failing item. The cable was considered mission critical equipment since a failure of the cable would prevent deployment of the connected weapon and completion of mission. Therefore, the cable was required to be tested to full threat levels. The cable was required to be subjected to the lightning direct effects waveform parameters (lightning direct effects environment of MIL-STD-464 parameters, full threat level, divided by 5 equal current paths) shown in Table 1.

Table 1 Lightning Test Parameters

Current Component	Description	Current Waveform Parameters			
		Amplitude	Action Integral	Charge Transfer	Time
A	Initial Stroke	2000,000÷5=40,000 A Peak ± 10%	2 x 106 A2s ± 20%	--	< 500 μsec
B	Intermediate Current	2000. ÷ 5 = 400 A Avg ±10%	--	10 ÷ 5 = 2 Coulombs Max	< 5 msec
C	Continuing Current	(200 to 800) ÷ 5 = 40 to 160 A Avg ± 20% A	--	200 ÷ 5 = 40 Coulombs +/- 20%	0.25 sec < T < 1 sec
D	Restrike	100,000 ÷ 5 = 20,000 A Peak ± 20%	0.25 x 106 A2s ± 20%	--	< 500 μsec

Lightning Test Pass/Fail Criteria

The cable was required to remain physically and functionally intact to support continued carriage after the strike and employment or downloading of the weapon. Due to the nature and low cost (approximately $2K) of the cable, reuse of the cable on subsequent missions was desired, but not required. The MIL-STD-38999 Type III Lanyard release connector was required to separate from the simulated weapon receptacle with less than 250 lbs. pull force (hand pulled). The ability to reconnect was desired, but not required. The A/A (Air to Air), A/G (Air to Ground), and video connectors were desired, but not required, to be readily removed (not fused) from their mated receptacles. The cable was required to retain continuity through signal paths, with no induced shorts.

Figure 2 Photograph of Lightning Test Setup

Damage to shielding was evaluated based on its potential for degradation of weapon employment, with shielding effectiveness measured from pre-test baseline levels. Other damage was evaluated based on its impact to weapon employment.

Lightning Tests and Test Results

The lightning testing were performed on two samples of the umbilical cables with composite connectors. The cable was connected to the mating connectors mounted on a plate (approximately 4 in x 4 in x 0.25 in) and a test fixture as used in the F/A-18 aircraft as shown in Figure 2. Test cables were subjected to Zone 3 currents at the amplitudes in Table 1 applied to the plate/shell of the receptacle mated to the MIL-STD-38999 Type III Lanyard release connector. During the test of the first sample, the test equipment failed to stop the waveform C after the required current, resulting in over 300 Coulombs vice the 40 Coulombs required for the test. After testing, the cables were inspected and tested for lanyard release, plate to plate resistance, continuity/shorts, and shielding effectiveness. The condition of the cables following the lightning test is shown in Figure 3. The lanyard release, plate to plate resistance, continuity/shorts, and shielding effectiveness for both cables was verified and determined to be acceptable.

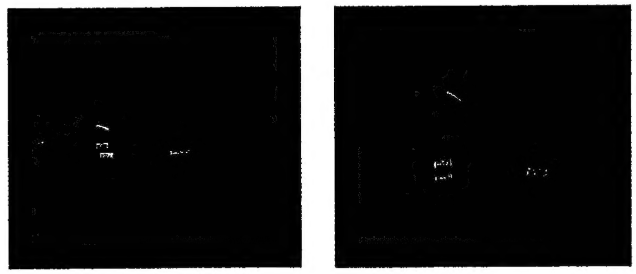

Figure 3 Cables after Lightning Test

5. STATIC PULL TEST

The composite connector was subjected to static tests to assure the connector type complied with separation requirements outlined in DOD-C-38999/31 and to provide a baseline of experience, including high pull angles, to support execution of the ejection tests. DOD-C-38999/31 states that the connector must release at a maximum force of 400 N (90 lbf) for a straight pull and 445 N (100 lbf) for a 15° pull at a pull rate not exceeding 13 cm/s (5.12 in/s). During the test, new connectors were used to baseline pull forces for specification pull angles (0°, 5°, 10° and 15° from vertical) and out of specification angles (17°, 18°, and 20°). Data from these tests were used to support ejection stand tests and future store separation tests by screening connector pull forces, exploring high pull angle connector performance (establishing expected values for pull force maximums and levels of jam resistance), and establishing wear patterns on the connector and receptacle.

Method of Test

The static test was designed to systematically test six connectors at pull angles ranging from 0° to 15° in 5° increments in both the pitch and roll directions. Each connector was pulled at a fixed rate of 1.6 in/s for 10 times at 0, 5, 10 and 15° and then as time and resources permitted, pulled at 17, 18, and 20 °. The test setup, shown in Figure 4, used a MTS test machine with an adapter plate to which the receptacle was mounted. The plate could be adjusted in orientation for both the angle to the vertical and the rotation of the mount. The pull angles were set by tilting the mounting fixture while the pull force was measured using a force transducer attached to the MTS machine. New receptacles were used and replaced after every 5 pulls to simulate the connector being put onto a new store. Pulls were done with the lanyard positioned perpendicular and parallel to the bail attachment. Pull angles were set for pitch up, pitch down, roll right, and roll left orientations relative to the major connector keyway. The tests were video taped for documentation purposes.

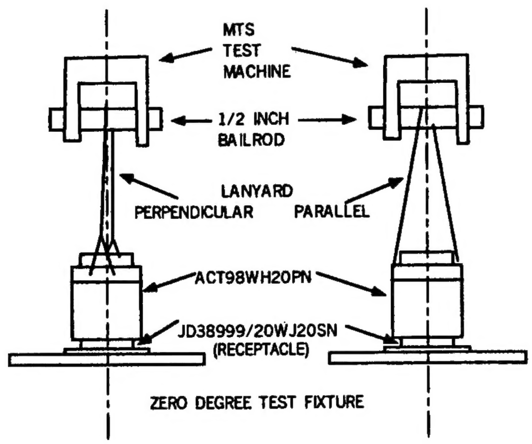

Figure 4 Composite MIL-STD-1760 Connector Static Test Setup

Cross Vendor Compatibility

At the first attempt of the static test, pull forces were considerably higher than those previously measured during tests conducted by the vendor and exceeded specification force differences (ranging from 30 to 100 lbf). Samples of available receptacles were measured to determine the worst case receptacle for pull forces, shown in Table 2, and that vendor receptacle was used for all further tests (static and ejection tests). An informal poll of connector vendors showed that, understandably, their standard practice had been to use their own receptacles for the required qualification tests. Two test attempts were aborted while trying to resolve this incompatibility.

Static Test Results

The static tests were used successfully to screen the connector performance in a simple and controlled manner and resolve a cross-vendor incompatibility prior to ejection testing. The pull forces recorded from the third set of connectors, shown in Figure 5, demonstrates that 89% of the releases were under the limits specified by DOD-C-38999/31 and ranged from 53 lbf up to 184 lbf (a maximum of 294 lbf for out of specification, 20° pull) under the worst case conditions used for the test. A typical pull force measurement is shown in Figure 6. As shown in Figure 5, high pull forces occurred within specification pull angles and low pull forces occurred on high pull

Table 2 Receptacle Dimension Variability

Receptacle	Major Diameter	Minor Diameter	Pitch Diameter
Size 25 DOD-C-38999/20 Specification	*1.6110/1.6250**	*1.5330/1.5510*	*1.5790/1.5890*
DTS20W25-20SN Deutsch 11139 9823B (New Metal)	1.613	1.549	1.578
ACT90W 20SN-3025 Deutsch 11139 9844B (New Composite)	1.608/1.613	1.545	1.583
JD38999/20WJ20SN Amphenol 3082070 9809 (New Metal)	1.620	1.552	1.587
JD38999/20WJ20SN Amphenol 3082070 9809 (Sample #39, Slightly Used)	1.621	1.552	1.587
JD38999/20WJ20BN Bendix H9504-170 (New Metal)	1.609	1.549	1.587
JD38999/20WJ20BN Bendix 3467240 9528 (New Metal)	1.618	1.550	1.587

*Note: Major diameter tolerance 0.0120 and Plating allowance 0.0020
Pitch diameter tolerance 0.0100

values. Subsequent analysis showed a previously undiscovered incompatibility with another vendor's DOD-38999/20 qualified receptacle. Tolerances allowed within the interface specification in outer diameter, inner diameter, and pitch diameter resulted in significant pull angles randomly. Pull angles between 15 and 18° were nominally accomplished. Pull angles at 20° resulted in a large piece broken on the inner coupling shell. After two broken connectors, 20° testing was halted.

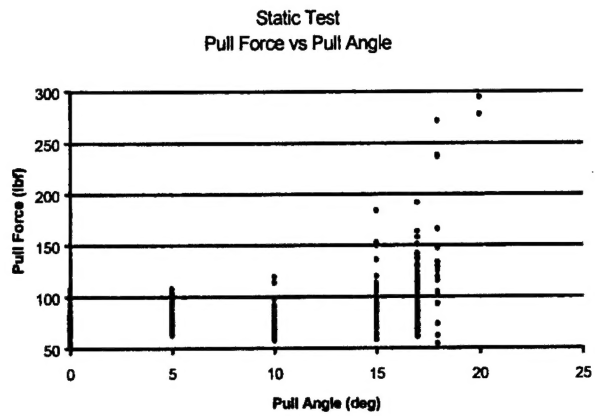

Figure 5 Static Test Pull Force vs. Pull Angle

The connectors and lanyards were examined and showed minimal wear (excluding the above mentioned damage from 20 ° pulls). Although high pull force anomalies occurred within the data sample, connector performance (Figure 7) was felt to be adequately characterized under "slow pull" conditions and was shown to be jam-resistant

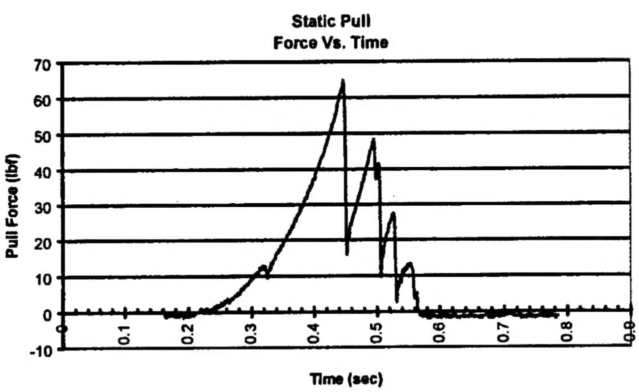

Figure 6 Typical Static Pull Test Force vs. Time

with the worst-case values tolerable for the intended application. The receptacles were examined for wear patterns to validate the planned replacement interval of every 5 drops during the ejection tests. The receptacles showed no visible wear with plating still intact, but this was contrary to results shown with other connectors. Since no wear was shown on the receptacles, receptacle replacement on the ejection tests was performed only when required by its condition.

6. EJECTION STAND TESTS

It was desired to find out how the umbilical would hold up in the real world environment of ejected releases. It would have been cost prohibitive to test the umbilical in the exact environment that it would see, so a plan to simulate the environment was devised. To this end, the umbilical was subjected to ejection tests on a test stand, shown in Figure 8. The objectives of this test were to verify proper performance during ejected releases, obtain pull force data for use in store separation analysis, and assess the umbilical's service life performance.

The planned scope of tests provided for six prototype umbilicals to be released 100 times each using a locally manufactured variable C.G. store. The variable C.G. store was used to generate store pitch and roll effects on the umbilical. These pitch and roll effects helped simulate the harsh environment that the umbilical would see during actual use. Another element of the test philosophy was to perform releases from two extreme receptacle locations across a variety of pull conditions that would provide a composite of conditions expected in fleet use. Sufficient umbilical samples and releases per cable were required to ensure that wear and failure modes were not masked by a "lucky" cable. Six umbilicals were chosen based on the number of umbilicals used during a previous NAWCAD separation test program where umbilical condition was well tracked and documented to provide a measure of comparison. The quantity of releases per cable was determined by the lanyard release endurance qualification limit of DOD 38999/31 (100 releases).

Method of Test

The test stand was set up with an adapter to accept an F/A-18 SUU-63 pylon. A BRU-32 bomb rack installed in the SUU-63 pylon in the same manner as if it was on the aircraft. The variable C.G. store was loaded on the BRU-32 using the 30 inch suspension hooks. The umbilical under test was then installed in the pylon and mated to the

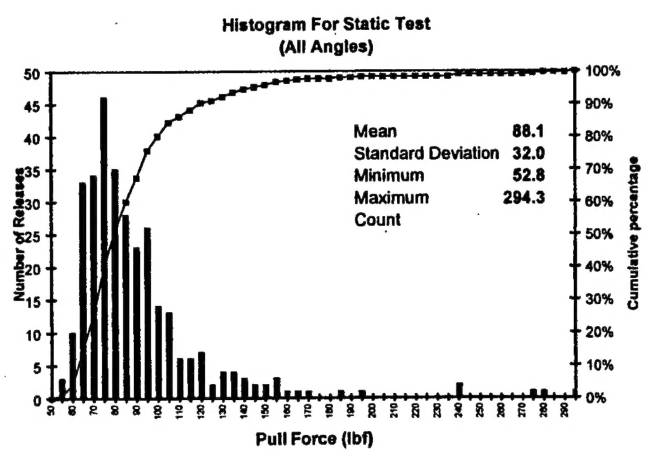

Figure 7 Static Test Histogram

store with the lanyard free to slide along the bail bar. For most test events the lanyard was put in an aft position on the pylon's bail bar to represent the worse -case in-flight initial condition (a few umbilicals were released with the lanyard in a different configuration, which will be discussed later). The BRU-32 was prepared for the

ejection by installing two Cartridge Activated Device's (CAD's) and unlocking the release mechanism. A high speed film and video camera's were started during a short countdown to the initiation of the ejection via a ground control panel. The store was ejected from a height of around four feet into foam padding. Once the bomb rack

Figure 8 Photograph of SUU-63 Pylon mounted to Ejection Test Stand with Variable C.G. Store

was made safe, the umbilical was visually inspected for any damage. An automated continuity and short circuit check was performed after every 5 releases for the first 50 releases and then performed after every 2 releases for the

Figure 9 Pull Angle Measurement Overlay on Video

- **Pull Force**. The pull force of the lanyard release connector was measured by strain gages on each end of the bail bar in a balanced bridge configuration. The bail bar was calibrated to measure up to 300 lbf. of vertical force and corrected for temperature drift on each drop. The calibration limit was determined by using data from the static tests to bound the pull forces expected.
- **Store Separation Characteristics**. The store separation characteristics were measured by three Linear Velocity Transducers (LVT's) mounted to the SUU-63 pylon via brackets and then attached by tape to the marked locations on the store before each ejection. The aft LVT was located 4.8" in front of the forward receptacle. The forward LVT's were located 4.3" in front of the forward ejector foot on the left and right side of the store. Store separation distance, store pitch, and store roll were derived from the measured data.
- **Pin Separation Time Mark**. The electrical disconnect time mark was measured by marking the continuity loss for a voltage measurement through two pins in the lanyard release connector when it separated from the store receptacle.
- **Pull Rate**. The pull rate was determined by the velocity provided by the aft LVT at the time of the electrical disconnect time mark.
- **Distance Traveled at Connector Separation**. The distance traveled at connector separation was determined by the distance traveled by the aft LVT at the time of the electrical disconnect time mark.
- **Hooks Open Time Mark**. The hooks open pulse was measured using an existing switch on the BRU-32 bomb rack.
- **End of stroke** (calibration drops)

These parameters were gathered real time using an AstroMed recorder with the data analyzed via a laptop computer running specialized AstroMed software and Microsoft Excel.

The locally manufactured store, with a weight of 819 lb, was designed to allow the center of gravity to be varied by adjusting ballast weights inside the store. The store's C.G. was adjusted to affect the pull angle of the connector by changing the angle that the store reaches as the umbilical releases. The C.G. position used during the test ranged from 15" to 25" aft of the forward suspension lug. The 15" position gave a store angle of 0° at lanyard connector release. The 25" position gave store angles of about 3 ° at lanyard connector release. C.G.'s inside those limits were used to vary the store angle between the minimum and maximum. The store had two receptacle positions at 9" and 15" aft of the aft suspension lug to represent the range of receptacle locations. Testing focused on the forward receptacle, which represented the majority of receptacle locations for the set of current 1760 weapons. The first fifty releases on the first umbilical were used to calibrate the locally developed store for pitch angle versus store c.g by performing 2 releases at each C.G. location, starting from 15" and incrementing the C.G. by 1/4". Once the calibration was complete, the test matrix was developed to try to achieve pull angles in several ranges. One hundred releases were completed on the first umbilical prior to the test of other umbilicals. Subsequent umbilicals were tested in groups convenient to the test effort. Although the test focused on achieving a specific pull angle for the umbilical lanyard, some flexibility was given to the controllability of the pull angle to achieve a close simulation of an actual release. The matrix was divided into 9 sections covering the main pull angles of 5, 10 and 15 degrees with each section having different tolerances above and below the desired pull angle.

Each release was monitored for several safety critical parameters. Limited data showed that structural failure of the ejection piston could occur at high piston velocities. Using data for the BRU-32, a limiting velocity of 23 ft/s was used to mitigate the risk of having a piston failure. During the calibration runs, the velocity of the piston (store) at the end of stroke was monitored. With the variable C.G. store, the velocity of the forward and aft pistons increased or decreased depending on the location of the C.G. Data from the LVT's was examined after each release to verify that the velocities were not approaching the cut-off value. Another safety critical parameter was the BRU-32 breech temperature. The BRU-32 was not designed to have multiple CAD initiations in a short amount of time. As a result, the test event execution rate was limited by the BRU-32 breeches cool-down time to remain below the cookoff temperature of the CAD's (Cartridge Activated Devices).

Results of Ejection Test

The ejection stand test provided some very interesting information about the umbilical and composite connector. The umbilical was found to be very survivable and indicated that it would have good service life performance. The umbilical was able to consistently survive the 100 releases and remain usable, including situations that the previous umbilical would not survive. The new umbilical showed good durability and resilience to catastrophic damage. On two occasions, the lanyard release composite connector became trapped between the store and pylon during loading evolutions, but remained usable with minor chipping of the inner barrel. Several thread segments from the engaging mechanism of the lanyard release composite connectors broke during release tests (occurred on 2 different umbilicals). The thread segment failures did not hinder the connectors performance in any noticeable area. The connector continued to mate to the receptacle and lanyard release with no changes in the release characteristics.

The composite MIL-STD-1760 lanyard release connector also yielded some very interesting results in relation to the pull force required to release. The lanyard release connector was previously qualified to the standards of DOD-C-38999/31. This standard states that the connector must release at a maximum force of 400 N (90 lbf) for a straight pull and 445 (100 lbf) for a 15° pull at a pull rate less than or equal to 13 cm/s (5.12 in/s). The connector must also pass a durability test during which the connector must release at a pull rate of 9.15 m/s (360 in/s). The pull force is not required to be measured during the durability test.

The pull force data collected during the test does not align with the qualification standard DOD-C-38999/31. This standard, however, and the maximum pull force allowed by it is commonly accepted as the environment that the connector will see. During the data collection of this test the pull angles were not forced to be at or under 15° nor were the pull forces typically smoothly developed. The photographic coverage showed that the lanyard typically skipped along the bail and often did not reach a nearly vertical position prior to connector release. During these ejected release tests, the connector was released with pull angles ranging from 1° to 34° and at a pull rate ranging from 75 in/s up to 135 in/s. The maximum pull force at the forward receptacle was 206 lbf at a 27° pull angle. The minimum pull force was 60 lbf at a 25° pull angle. This leads to the conclusion, along with the histogram plot in Figure 10 and the 3-D scatter plot of pull force, pull rate, and pull angle in Figure 11 that the pull force is a random function of the pull angle. This is contrary to what was expected. Common thought was that as the pull angle increased or decreased from vertical, the pull force followed. The data collected from this test shows that this is not the case for this connector. The inability to constrain pull angles to 15° or to smoothly develop the pull force or angle with a bail bar arrangement is significant and should

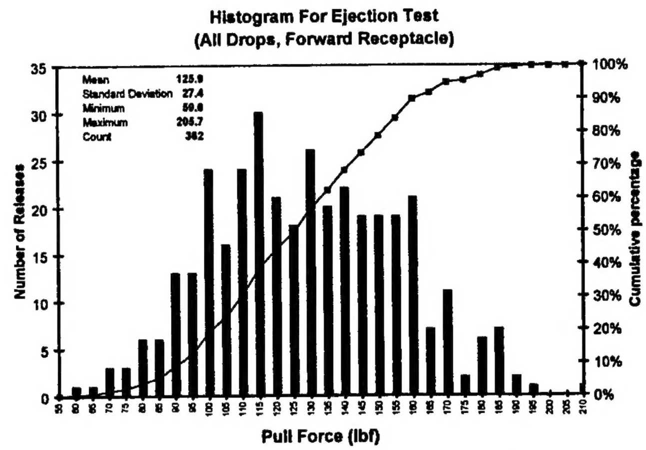

Figure 10 Histogram for Ejection Test for Forward Receptacle, All Drops

be understood when comparing this data with the qualification standard of DOD-C-38999/31. Moreover, Ejected releases typically showed higher pull forces overall than static releases as well as a wider spread of values. Since the qualification standard bases its pull forces measurements on "slow" pulls, it lacks in determining the pull force that the connector will be faced with in its operational environment. In future efforts, expected pull

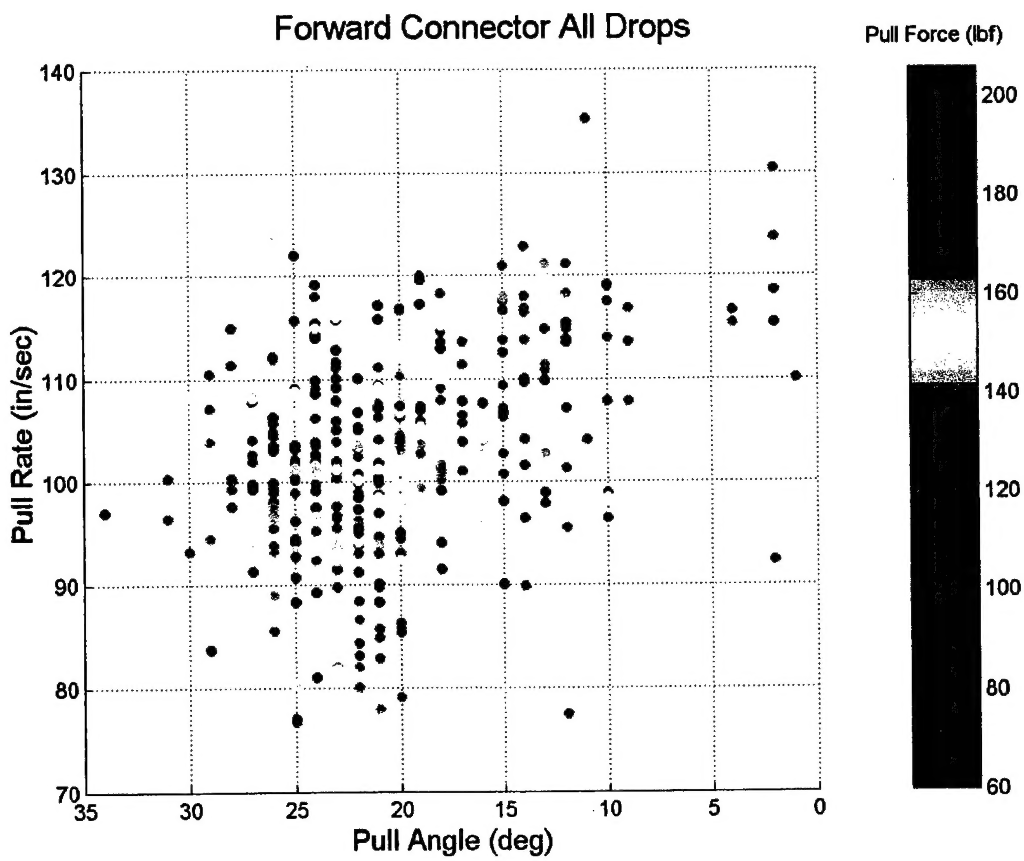

Figure 11 Scatter plot of Pull Force, Pull Rate, and Pull Angle

force characteristics should be empirically determined with a statistically significant number of releases in an environment as close to the operational environment as practical.

7. Captive Carriage Flight Tests

After completion of the ejection tests, four of the umbilicals were subjected to captive carriage flight testing in a post-release configuration to evaluate survivability in the F/A-18 flight environment. Of specific concern were the durability of the Kevlar lanyard, composite connector, and the flexible cabling, as well as carriage characteristics of the 90° lanyard release connector in concert with the flexible cabling. There was concern that the airstream dynamics would produce excessive twisting of the umbilical and repeated impact with the pylon, resulting in material failures.

Method of Test

The first flight was a dedicated mission with a test matrix consisting of 360 ° rolls, 60 ° bank to bank rolls, steady heading sideslips, wind-up/down turns, dive/rolling pull outs, and level acceleration/deceleration runs. On-board cameras (at 24 fps) were used to view the umbilical carriage characteristics. Post-flight inspection of the umbilicals and pylon area was conducted prior to their removal. After review of the umbilical captive carriage characteristics from the film, the umbilicals continued to be carried on 12 subsequent flights which were not dedicated missions (typically chase missions for other tests) and did not include camera coverage. The cables were flown a total of 32.3 hrs. Cable condition was monitored via visual inspections and automated continuity/short testing and tracked throughout the flight test program.

Captive Carriage Test Results

The umbilical demonstrated very stable and desirable carriage characteristics, typically retracted in the pylon with some small flexure during some maneuvers. No adverse cabling dynamics were indicated. The lanyards showed no visible increase in wear above that experienced in the ejection tests. After 22.4 hrs, one lanyard knot became loose. Minor wear and tear was shown on the cable progressively through the flight test. All four umbilicals passed the automated continuity/short testing.

8. Post Certification Use of Umbilical

The umbilical was subsequently used on various 1760 stores flight test after it was certified for use on the F/A-18. Its first use was with the flight test of the Mk83 JDAM separation test. The previous umbilical that was available had a problem with jamming on the weapon receptacle during release. When the connector jammed, forces in excess of 500 pounds were possible. The potential for high forces caused a concern with store release. The ground test data for the new umbilical showed that it would not generate the excessive forces due to the jam resistance of the material it is manufactured from. The composite connector will break and release instead of jamming on the receptacle. In light of this data, the newly designed umbilical is the only umbilical that is certified to be used with the Mk 83 JDAM. In addition to the Mk83 JDAM, the umbilical is also used on all F/A-18 E/F 1760 Stores. To date, it has been used for Mk84 JDAM and JSOW separation, as well as SLAM-ER captive carriage. The characteristics of this umbilical and the data gathered during the ground test will become increasingly important as lighter 1760 stores are implemented on the F/A-18.

9. Conclusions

The development and testing of the U.S. Navy F/A-18 replacement MIL-STD-1760 umbilical resulted in several conclusions with regard to the composite lanyard release MIL-STD-1760 connector and its separation and function. The DOD-C-38999/31 qualification requirements do not assure jam resistance or excessive pull forces at high pull angles or realistic ejected release pull rates. Separation prediction capabilities should use statistically significant empirical data vs. DOD-C-38999/31 qualification pull force values, unless the application drives a pull rate of 13 cm/s or slower. The use of a bail bar for lanyard connector release will result in uncontrolled and varying pull angles with the release typically occurring at high pull angles (at or above the DOD-C-38999/31 specification value of 15°). Composite lanyard release connectors provide damage tolerant performance and are suitable in a lighting environment. Kevlar lanyards are suitable for use on DOD-C-38999/31 lanyard release connectors. The use of ground tests to help characterize the possible pull forces of a connector are useful if the test closely simulates the environment that it will encounter. In summary, the 1760 umbilical was subjected to a multitude of tests that demonstrated that it was suitable for the F/A-18 environment and will satisfy the requirements of MIL-STD-1760 stores.

References

[1] Test Report LT-97-1442 Lightning Tests on Deutsch Series ACT and DTS Metal and Composite Connectors, 25 Jul 1997.

[2] Radio Technical Commission of Aeronautics, RTCA/DO-160C, Environmental Conditions and Test Procedures for Airborne Equipment, Section 22 – Lightning Induced Transient Susceptibility, June 1992.

[3] MIL-STD-464 Department of Defense Interface Standard Electromagnetic Environmental Effects, Requirements for Systems, 18 Mar 1997.

[4] DOD-C-38999J Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect , Environment Resistant, Removable Crimp And Hermetic Solder Contacts, General Specifications For, 25 May 1993

BIOGRAPHIES

Susan Jahn is currently the F/A-18 Weapons System Integration Air to Ground Functional Lead with the US Naval Air Systems Command at the Naval Air Warfare Center Aircraft Division. She was an aircraft/weapon compatibility flight test engineer with the US Naval Air Systems Command at the Naval Air Warfare Center Aircraft Division, Air Vehicle/Stores Compatibility Division at Patuxent River, MD. She earned a Bachelor of Science degree in Electrical Engineering from the University of Maryland, College Park in 1986. She has been conducting aircraft/stores compatibility testing for the last eleven years on fixed and rotary wing aircraft. Prior to working for the U.S. Naval Air Systems Command, Mrs. Jahn worked for the ManTech Systems Company on a variety of airborne and ship systems in support of the U.S. Navy. She is a member of the SAE Aerospace MIL-STD-1760 User Task Group and the Miniature Munitions/Store Interface Task Group. She has a total of fifteen years of experience with the Department of Defense. She is married to Douglas W. Jahn. They currently reside in St. Inigoes, MD with their three children Kallie, age 7, and Katie, age 5, Kassi, age 6 months.

Greg Miller is an aircraft/weapon compatibility flight test engineer with the U.S. Naval Air Systems Command at the Naval Air Warfare Center Aircraft Division, Air Vehicle/Stores Compatibility Division at Patuxent River, MD. He earned a Bachelor of Science in Mechanical Engineering with an Aerospace Option from Oklahoma State University in 1997. He has been conducting aircraft/stores compatibility testing since June of 1998 on both fixed and rotary wing aircraft. He is married to the former Amy K. Negelein of Pawnee, OK. They now reside in Dameron, MD.